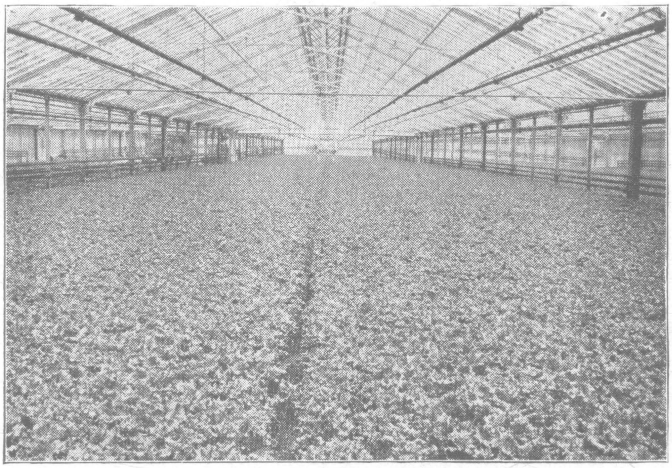
BULLETIN 408 AUGUST, 1927

Chemical Fertilizers For Greenhouse Lettuce

J. H. Gourley



A modern range of lettuce

OHIO
AGRICULTURAL EXPERIMENT STATION
Wooster, Ohio

This page intentionally blank.

CONTENTS

This page intentionally blank.

Chemical Fertilizers For Greenhouse Lettuce

J. H. Gourley

SUMMARY

According to statistics, Ohio has more acres of greenhouse devoted to the production of vegetables than any other state. Of the vegetables grown, lettuce ranks first; often two crops being grown in a season, followed by cucumbers or tomatoes.

The experiments reported in this bulletin were designed to determine to what extent chemical fertilizers, lime, and green manures, without the addition of animal manures, can be relied upon to produce leaf lettuce.

Three series of experiments are included, referred to as Series, A, B, and C. In Series A fertilizers are added to a compost soil to which manure is applied at the rate of about 30 tons per acre annually. The basis of the original soil was the Wooster silt loam, which when untreated is acid in reaction. The soil of Series B is composed, roughly, of half clay subsoil and half surface soil of the same general type that formed the basis of Series A. Fertilizer treatments have been added to some of the plots but no manure has been used on any of the plots in this series. Series C is composed of surface soil only to which are added lime, artificial fertilizers, and manures, as described in the text. All of the soils now show an alkaline reaction.

A poor soil was used in Series B for the purpose of determining whether such a soil could be improved with fertilizers to the point of producing satisfactory commercial crops, for no grower would be likely to move a soil of this character into his houses.

Eight crops of lettuce are reported in Series A, by which it is shown that no combination of fertilizers used produced a yield superior to the yields from the compost soil and manures alone. Hence for the conditions under which these crops were grown, manure supplies an abundance of all the elements essential for leaf lettuce.

Certain chemical fertilizers and a green manure crop of soybeans annually, however, have produced satisfactory crops of lettuce thruout the four years of these experiments in both Series B and C. The average yield in Series C was at the rate of 38,669 pounds per acre for manure and 32,426 pounds per acre for a ton of a 3-12-4 fertilizer per acre, altho a greater amount of nitrogen was added in the manure, which does not make the treatments quite comparable. The last crop on the manured plot was only 9 percent higher in yield than that on fertilized Plot 2.

A complete fertilizer composed of nitrate of soda, acid phosphate, and muriate of potash proved superior to a single salt alone or to a combination of either nitrogen and phosphorus or nitrogen and potassium.

A ton of the complete fertilizer per acre, applied at one time, gave higher yields than half this amount, but the difference was not sufficient to make a clear case for the practice. Some injury to roots resulted from a ton applied immediately prior to setting the plants, hence it is recommended to divide this quantity into two or three applications per year.

The strongly alkaline soil used in these experiments has resulted in good yields of lettuce provided ample plant food materials were present. It was only when a pH value of nearly 8.5 was reached that there was an indication of injury.

In general, it is suggested that where it is difficult for the grower to obtain manure, he may expect practically as good yields of lettuce on a soil of this character from half the usual quantity of manure supplemented with one-half ton of a 3-12-4 fertilizer.

Many other combinations and amounts of fertilizers, as well as chemicals with reduced amounts of manures may be used. Such treatments were not included in this set of experiments, but it is hoped that the grower of greenhouse lettuce facing a deficit of manure may be encouraged by the results so far secured from these artificial fertilizers alone.

INTRODUCTION

The purpose of the experiment here reported should be made clear at the outset. It anticipates an increase in the use of chemical fertilizers in growing greenhouse crops and a decrease in the use of animal manures due to their scarcity and high cost. Indeed, practice is rapidly changing already in this regard.

It is traditional among greenhouse men that an abundance of stable manure is essential for success in the culture of greenhouse crops. This is based on experience, but a somewhat one-sided experience, because the value of greenhouse crops has been sufficiently high to warrant large expenditures in the purchase of manure. Hence, no widespread attempt has been made to determine to what extent manure can be replaced by other forms of plant food materials, altho a few experiments on it have been reported. As animal manures become more difficult to secure at any price there will be a need for such information as these experiments with chemical fertilizers are designed to supply.

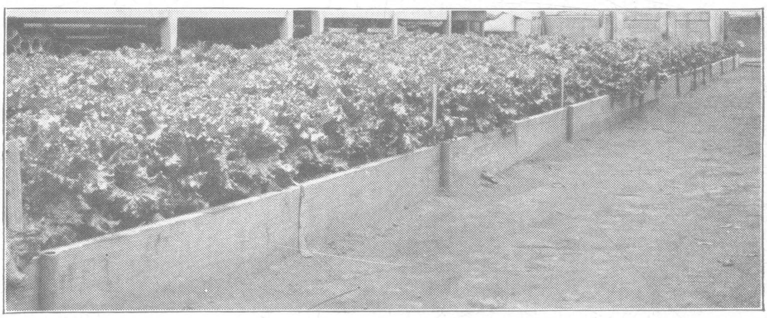


Fig. 1.—Series C, November 18, 1926
Plot 2 at left, Plot 8 at extreme right.

Ohio is one of the few states in which more glass is being erected each year for the growing of both vegetables and flowers, and it is estimated that there is now between 500 and 550 acres of glass in this State devoted to these crops.

Aside from securing the most desirable variety of vegetables to grow, the most fundamental consideration is the soil. Other problems, such as disease and insect control, are more acute at times, but without an abundance of plant food materials and congenial soil conditions high production cannot be maintained. Because of the inequalities of soil and the consequent length of time that is necessary to secure satisfactory information, it is important that experimental work on this problem of soil fertility precede the actual need for its solution by several years.

Since there is so little available information on the use of chemical fertilizers in the growing of greenhouse crops, this preliminary report is made of their use in the growing of leaf lettuce, even tho several features of the experiments are incomplete.

A crop of tomatoes occupied these plots during the spring and early summer, but, due to injury by disease, no report is yet ready on the response of this crop to the fertilizer treatments.

EXPERIMENTS WITH VEGETABLES OUT-OF-DOORS

The same problem has been under investigation by the Station for the last 12 years with certain other vegetables grown in the Marietta trucking district and for a somewhat shorter time on the soil at Wooster. That is, can vegetables in general be successfully grown with chemical fertilizers and cover crops to compete with those grown with manure under like conditions?

While lettuce is not grown in the Marietta experiments, it may be said, for the sake of comparison, that the highest average yields of tomatoes, cucumbers, and sweet corn were secured with animal manures (16 tons per acre) together with lime. But an annual application of 1220 pounds of a 4-10-4 fertilizer (800 lb. acid phosphate, 320 lb. nitrate of soda, and 100 lb. muriate of potash) gave nearly as large yields and the net returns were higher over the 12-year period. With cabbage both the highest yields and returns were secured from the chemicals. This work is on a soil that is naturally low in fertility and organic matter and the returns have been surprisingly satisfactory when judged in the light of previous notions of the subject. It is far from the purpose of the writer to suggest that manure should be displaced by chemicals, but rather he would point out the possibilities of at least a partial replacement when this becomes necessary.

MANURE—ITS VALUE AND PURPOSE

In the past animal manures were considered all sufficient in the maintenance of the fertility of the land as well as for providing a good mechanical condition. A full understanding of the nature of manure was lacking and there was a sort of mystery about manure which resulted in extravagant notions regarding its superiority to all other sources of plant food materials. Nowhere was this more pronounced than with those who grew crops intensively, such as in the market garden and greenhouse.

Recent interpretation and analysis of the long-time experiments in the use of manure on field crops are robbing this material of much of its supposed virtue and are crediting it with little or nothing beyond the actual elements of fertility that it carries. Thorne (11)* has recently reviewed the work of the agricultural experiment stations of England (Rothamsted), Pennsylvania, Ohio, Indiana, and Missouri. He concludes that, "The experiments here reported show that it has been possible, by the use of chemicals alone, to maintain the yields of farm crops for periods of 20 to 30, 40 and 70 years on a parity with the yields from applications of farm manures containing much larger total quantities of the essential chemical elements, and therefore that the addition to the land of any organic matter for the sake of the carbonaceous material such matter may contain is altogether unnecessary; the outcome warranting the assumption that the larger root growth, which may be obtained as effectively from the elements in chemicals as from those in manure, furnishes all the organic carbon required for bacterial functioning". He also states, "Where any greater residual effect has followed manure than chemicals it appears to be fully explained by the larger dosage of essential elements given in manure than in chemicals. Such effect is therefore obtained at the sacrifice of immediate returns".

This conclusion will doubtless be viewed with surprise and considered revolutionary by the vegetable growers in particular. Thorne points out, however, that the market garden is not quite parallel with the field condition both because of the smaller relative amount of crop residue that is returned to the soil and of the smaller amount of manure that is added, but his contention in general adds support to the findings already recorded from the gardening work at Marietta (5) and to the preliminary results here reported with lettuce in the greenhouse.

THE SOIL USED

For a number of years experiments had been under way in the greenhouses to determine the value of various fertilizer combinations for lettuce, tomatoes, and cucumbers. The soil on which they

*Numbers refer to Literature Cited page 22.

were applied was a compost of field soil, sod, and manure. Apparently it was sufficiently fertile to supply the necessary food materials, for no consistent or significant increases were obtained from the use of fertilizers. Some of the results of the earlier experiments have been published (Buls. 43, 281) and are not here reviewed.

Series A.—The situation is illustrated in Series A of the later experiments, which shows no returns from any combination of fertilizers used. This series was started in 1919, but results are reported only for the same years as Series B and C. Therefore, for experimental purposes, it seemed desirable to use soils much lower in fertility than these composted ones, and field soil was removed to the greenhouse and Series B and C were started in 1922.

Series B, located in the same house as Series A, is composed of eight plots. The soil was taken in the fall of 1922 from the site of a new building (Thorne Hall) then under construction. The soil selected was an admixture of surface and subsoil, at least half of the latter. This soil is classified as Wooster silt loam and the subsoil is of a heavier character. When untreated it gives a distinctly acid reaction. In the beginning it showed a yellow color when watered and was quite compact, in striking contrast to the rich compost soil in Series A. No manure has been added to any of the plots. Ground limestone was applied at the rate of 1000 pounds per acre to all the plots before the first crop was planted but none has been added since. Soybeans were grown each summer for a period of about six weeks after the tomatoes were removed, and they were then cut, chopped up, and the product of each plot spaded into the soil. By this means organic matter was added. Fertility was provided by chemical fertilizers.

While no grower would use such poor soil in his greenhouse, it was our object to determine whether such a soil could be built up with green manure and chemical fertilizers, and if so how long it would require.

Series C was started in the fall of 1923, one year later than Series B. It consists of surface soil removed from a point adjacent to that used in Series B. It was naturally better than the other as no subsoil was taken, but the response was scarcely equal, a fact that is not yet explained.

Plot 1 was modified by making it up of 3 parts soil and 1 part sand. Only one plot received lime, but soybeans were grown and spaded into the soil as described for Series B.

THE PLOTS

Each plot in the three series is 6 by 7 feet (42 square feet) and accommodates 90 plants set 8 by 8 inches. A pine board partition separates the plots. Two rows of tile running the length of the beds are used for subirrigation at times and for steam sterilization of the soil in summer.

GROWING THE PLANTS

The variety of lettuce used in all of these plots is a special selection of Grand Rapids produced in the Station greenhouses. In color it is identical with the commercial strains but it is more uniform in type than any that has been secured on the market. The seed was sown in flats and when the first true leaf appeared the plants were transplanted into other flats and spaced approximately 2 inches apart each way. The plants were set 8 inches apart in the beds and surface watered.

A typical fall crop is as follows: seed planted Oct. 7, first transplanting Oct. 15, planted in beds Oct. 23, and cut for market Jan. 20, making about 3½ months from seeding to harvest. Sometimes the seed was sown the fore part of September and the crop cut about the first of December. The second or winter crop was sown about the middle of November, transplanted in about two weeks, set in beds in about seven weeks, and harvested about the middle of March. This crop was sometimes a week or two earlier, depending upon the date of harvesting the first crop.

The plants were cut uniformly at the surface of the soil and any discolored outer leaves removed. They were then weighed in kilograms and fractions thereof and a blanket increase of 10 percent added to account for the actual market weight after washing. The weight per plot was converted into pounds, as recorded in the tables.

EXPERIMENTAL RESULTS

SERIES A

As already described this soil is a compost and manure was added annually at the rate of about 30 tons per acre. Eight consecutive crops of lettuce are here reported, altho the treatments have been in progress since 1919. As can be seen in Table 1 there was no response to the various fertilizer combinations. This confirms the previous work at the Station (7, 8, 6) and also the work of Beach and Hasselbring (1, 2) and others. Evidently all the plant

TABLE 1.—Series A, the Effect of Various Manure and Fertilizer Treatments on the Yield of Grand Rapids Lettuce*

Pounds of washed lettuce per plot of 42 sq. ft.

Plot	Treatment, pounds per acre		Date of harvest								Average	Average yield per acre
			Dec 1 1923	Feb. 28 1924	Dec. 11 1924	Mar. 17 1925	Dec. 10 1925	Mar. 15 1926	Nov. 17 1926	Feb. 24 1927		
			Lb.	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*
1	Nitrate soda Acid phosphate	220 480	27.10	27.83	26.75	31.81	29.88	38.67	37.72	33.99	31.72	32,893
2	Acid phosphate Muriate potash	480 180	29.08	33.59	27.63	35.58	32.30	36.60	38.59	33.82	33.40	34,435
3	Untreated		29.41	35.17	29.58	35.73	36.36	37.80	26.23	34.82	33.14	34,366
4	Sulfate ammonia Acid phosphate	170 480	29.12	35.44	27.45	31.87	35.66	35.73	37.41	31.92	33.08	34,303
5	Nitrate soda Acid phosphate Muriate potash	220 480 180	27.03	35.23	25.98	31.81	34.28	41.65	36.85	36.74	33.69	34,936
6	Untreated		27.45	37.69	27.25	35.67	34.84	38.59	37.94	36.02	34.43	35,703
7	Acid phosphate	480	26.75	34.74	28.73	36.77	33.31	32.57	37.15	35.02	33.13	34,355
8	Steamed bone	265	29.70	33.72	26.60	34.22	34.23	31.11	38.29	33.38	32.65	32,764

*For description of soil see page 7.

food materials essential for a full production of leaf lettuce were provided in the manured soil, but no harmful effects are yet manifest from the addition of these chemical fertilizers. The yield of the unfertilized plots averaged between 17 and 18 tons per acre, or in the neighborhood of 800 pounds to 1000 square feet of bed.

It will be seen that the yield of the last four crops was somewhat higher than of the first four. That this was due to a general improvement of soil conditions is not beyond question, yet the greatest increases were in two of the plots to which nitrogen was added. Plot 4, however, did not show an increase. For instance, the two unfertilized plots increased 4 and 15 percent, respectively, while Plots 1 and 5 increased 23 and 24 percent, respectively. Acid phosphate (Plot 7) failed to account for an increase over the average of the unfertilized plots.

SERIES B

This soil, already described, unlike that in Series A, gave a definite response to the fertilizers from the first. No plot was left entirely untreated, for all received a light application of lime at the beginning and on each a cover crop of soybeans was grown annually and returned to the soil. The first crop was very inferior but the second crop showed a rapid improvement which has been maintained but has not been increased. The average of the untreated plots in Series A was 54 percent higher than in Series B where no manure was applied, but the average of all the treated plots in Series A was only 22 percent greater than in Series B. This indicates the striking effect of chemical fertilizers, lime, and a green manure crop on a soil of poor texture and low fertility, unable of itself to produce even a mediocre crop. In fact this response was entirely unlooked for at the beginning of the experiment. It also illustrates, of course, that, in the production of leaf lettuce under glass, the rich compost soil was superior (by about 20 percent) to this soil treated with fertilizers.

In harvesting the plots in both Series B and C the rule was to harvest all the plots when the best one was ready. These were Plot 8 in Series B and Plot 4 in Series C. The other plots would have given a better yield if they had been allowed to remain longer, but the element of earliness, or quick maturity, as well as yield was considered important. The lower yield of all the plots at some harvests than others was due to the haste in planting the succeeding crop, so that a maximum crop was sacrificed to some extent for the sake of having the next crop occupy the beds. These two points should be borne in mind when critically examining the tables of yield.

There is a lack of consistency in certain particulars, more especially for the first few crops. For instance, the checks were not always the lowest in yield, altho in the grand average they are notably so. The other plots did not always hold the same rank in order of yield, but by ranking them in the order of the percentage increase over the average of the two checks, a fairly satisfactory conclusion can be drawn regarding the relative efficiency of the treatments.

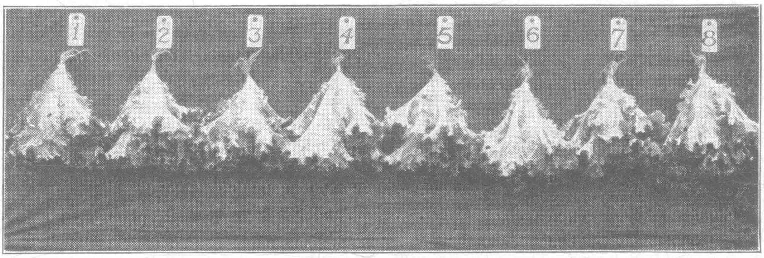


Fig. 2.—Series B, December 12, 1925

A typical plant from each plot. There have not been as marked differences in the plots in this series as in Series C.

The treatment that produced the largest yield most of the time was a 3-7-9 fertilizer applied on Plot 8 at the rate of one ton per acre. This treatment like the others was all applied before setting the first lettuce crop in late summer or early fall. As a result the rootlets of the young plants were sometimes injured and occasionally a few plants were reset. In practice it would be better to divide this quantity of material into two or three applications during the year rather than to apply all at one time, for obviously under these conditions an application of 1500 to 1700 pounds is the maximum that should be applied to this soil at one time.

Plot 8 had the lowest yield of any in December, 1925. The appearance of the plants did not indicate this and it is possible that the figure (28.67 pounds) is an error of recording. In appearance and quality the lettuce in this plot was nearly equal to that grown on the compost soil.

The next highest yield in this series was from Plot 5, which received half the treatment of Plot 8. The yields in this plot were quite consistent and averaged only 12 percent less than Plot 8, while in three crops of the nine they were slightly higher than Plot 8.

TABLE 2.—Series B, Effect of Fertilizers on the Yield of Lettuce Grown on a Soil of Low Fertility*

Pounds of washed lettuce per plot of 42 sq. ft.

Plot	Treatment, pounds per acre	Date of harvest									Average	Increase	Av. yield per acre
		Apr. 25 1923	Dec. 23 1923	Mar. 20 1924	Dec. 28 1924	Mar. 31 1925	Dec. 14 1925	Mar. 17 1926	Nov. 18 1926	Feb. 24 1927			
		Lb.	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	%	*Lb.*
1	Nitrate soda 220; Acid phosphate 480	24.02	25.05	28.13	22.15	19.98	29.61	25.59	30.42	26.88	25.76	17.4	26,713
2	Acid phosphate 480; Muriate potash 180	16.73	25.60	23.49	25.38	24.15	30.94	25.16	31.77	27.99	25.69	17.1	26,640
3	Untreated	10.75	23.07	17.76	23.89	15.59	29.88	19.75	29.87	20.68	21.25	....	22,036
4	Sulfate ammonia 170; Acid phosphate 480	13.71	25.03	28.55	23.34	23.78	29.83	25.51	30.85	26.71	25.26	15.1	26,194
5	Nitrate soda 220; Acid phosphate 480; Muriate potash 180	23.01	26.24	27.38	27.82	26.85	31.70	24.31	32.27	30.55	27.79	26.6	28,818
6	Untreated	10.69	26.09	17.58	26.92	22.77	28.79	21.59	28.86	20.32	22.62	....	23,456
7	Acid phosphate 480	8.18	25.91	20.69	26.57	26.15	30.31	24.86	29.87	24.70	24.14	10.0	25,033
8	Nitrate soda 440; Acid phosphate 960; Muriate potash 360	19.70	27.01	33.69	26.86	31.96	28.67	36.41	32.64	35.40	30.26	38.0	32,764

*For description of soil see page

No plot is now in progress where this amount of fertilizer is used for each of the two lettuce crops, but these results warrant the suggestion that about one-half ton of such a fertilizer is all that can be profitably used on this soil at one application. As will be seen, the same inference is drawn from Series C.

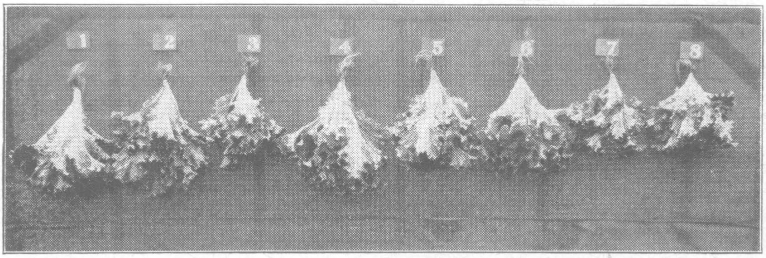


Fig. 3.—Series C, February 23, 1927
A typical plant from each plot.

Of the other plots, there was little choice between 1, 2, and 4, all of which carry acid phosphate in combination with one other salt; but all were superior to Plot 7, which is supplied with acid phosphate alone. As shown in the unfertilized plots and also in these three plots, there was considerable variation in the yield from year to year. Plot 8 outyielded the others in six of the nine crops, altho the average yield was slightly higher for Plot 1. Judging from the superiority of the plot receiving acid phosphate alone over the untreated plots and of the complete fertilizer plots over any treatment of either one or two elements it would seem that a complete fertilizer is desirable for greenhouse lettuce under such conditions as obtain in both Series B and C of these experiments.

SERIES C

Series C is of even greater interest than either of the other two. The plots were more consistent in their behavior than in Series B. Some additional features were also included. It is not yet clear, however, why the untreated plots averaged higher in yield in Series B than in Series C, since the soil in C was decidedly better at the start. From the first there was a decided difference in response to the various treatments. Figure 3, which shows a representative plant from each plot, illustrates the striking differences in growth.

By way of comparison, we see that the unfertilized plots in the compost soil, Series A, averaged 35,034 pounds per acre; in Series B, 22,746 pounds; and 19,651 pounds in Series C, the one check plot. It may be more than a coincidence that the untreated plots in Series B, which was limed at the beginning of the experiment, yielded very nearly the same as the one limed plot in Series C, altho an analysis of these plots in Table 5 would not suggest any outstanding difference in hydrogen-ion value.

Examining Plots 1 and 2, which were treated with a ton of complete fertilizer per acre and hence may be compared with Plot 8 of Series B (altho the fertilizer analysis differed), it is seen that the three plots yielded nearly the same. Plot 2 outyielded Plot 1, with a single exception. This may be accounted for largely on the ground that Plot 1 was made up with ¼ its bulk of sand. An additional factor has also been mentioned—namely, that more chlorosis, or leaf spotting, developed in this plot than in any other, unless it be Plot 3, which necessitated the cutting away of some of the outside leaves. The yield, however, was very satisfactory and when it is realized that no manure was added to this soil, the results were surprisingly good, emphasizing again that chemical fertilizers can be used to supplement manure and will produce good crops for at least several years without any animal manure.

The average yield of Plot 2 for these seven crops was 16 percent higher than Plot 6, receiving one-half the quantity of chemicals. In Series B the difference was about 9 percent.

Acid phosphate used alone on Plot 5 gave almost the identical average yield secured in Series B, Plot 7, where it was used in a smaller application. While the yield was distinctly better than that on the untreated plot, yet it was so inferior to the yields of the plots receiving a complete fertilizer that the lesson here is clear.

Nitrate of soda used alone gave such conspicuously low yields thruout that its use alone is completely barred. Only twice did this plot yield as well as the untreated ones, indicating an actually depressing effect. So here, with a leafy crop, where nitrogen alone might be expected to be very beneficial, it failed completely. This is not in keeping with the findings of Lloyd (10) on raised benches.

Finally, we have for comparison Plot 4, which received manure only. It is in reality practically a duplicate of the unfertilized plots of Series A. This plot is very useful as a standard of comparison and for determining to what extent, with this particular soil, artificial fertilizers and green manure can replace animal manures. Here we find that this manured plot (Plot 4) averaged 97 percent higher in yield than the untreated plot (green manure only, Plot 7) and 19 percent higher than Plot 2, which gave the highest average production secured from chemicals alone. However, in the last crop (Feb. 23, 1927) the difference between Plot 2 and Plot 4 was only 9 percent.

Frequently the grower does not realize the amounts of the chemical elements that are applied in manure, as discussed on page 6. The following figures give a comparison of the amounts of nitrogen, phosphoric acid, and potash that were applied on certain of the plots under consideration:

TABLE 3.—Comparative Amounts of Nitrogen, Phosphoric Acid, and Potash Applied in the Manure, and Certain of the Complete Fertilizer Treatments

Series and Plot		Treatment		
		N	P_2O_5	K_2O
		Lb.	*Lb.*	*Lb.*
Series A, Plots 3 and 6 Series C, Plot 4,	30 tons manure.............	220–400	150–180	200–400
Series B, Plot 8,	440 lb. nitrate soda. . ... 960 lb. acid phosphate . ... 360 lb. muriate potash...... ...	68	150	180
Series C, Plots 1 and 2,	1 ton 3-12-4 ..	60	240	80

The comparative yields from Plots 4 and 2 make it clear that a better response can be secured on this soil from the use of 30 tons of manure than from one ton of a 3-12-4 fertilizer. On the other hand, the results from the fertilizer are so good that less concern need be felt over the waning supply of manure than has usually been felt. They would give weight to the suggestion that an application of about 12 or 15 tons of manure and 1500 pounds of a complete fertilizer per acre might replace, at least on some soil types, the heavy manurial treatments commonly followed.

LETTUCE PRODUCTION ON AN ALKALINE SOIL

The literature on the value of liming soil for the production of lettuce is not wholly in agreement. Hartwell and Damon (9) made extensive trials with a number of crops to determine their response to liming. In reporting the results an attempt was made to indicate the relative degree of benefit from liming. In their classification the rating of head lettuce indicates that without applications of lime this crop is liable to be unsatisfactory. "Even if nothing is known regarding the requirements of the soil it is much wiser to add lime as a preparation for such crops than to attempt to grow them without doing so".

TABLE 4.—Series C, Effect of Manure, Lime, and Chemical Fertilizer on the Yield of Lettuce*

Pounds of washed lettuce per plot of 42 sq. ft.

Plot	Treatment, pounds per acre	Date of harvest							Average	Increase	Av. yield per acre
		Mar. 10 1924	Dec. 28 1924	Apr. 2† 1925	Jan. 19 1925	Mar. 16 1926	Nov. 22 1926	Feb. 23 1927			
		Lb.	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	%	*Lb.*
1	1 ton 3-12-4 ¼ soil is sand	39.19	36.19	24.90	24.17	32.18	17.81	27.73	28.88	52	29,948
2	1 ton 3-12-4	44.59	40.59	20.93	25.79	33.77	21.78	31.42	31.27	65	32,426
3	2 tons limestone	31.59	29.59	11.97	17.52	22.10	19.43	20.25	21.78	15	22,586
4	30 tons manure	48.88	44.88	27.78	35.93	38.59	30.58	34.36	37.29	97	38,669
5	750 lb. acid phosphate	37.98	34.98	11.82	16.70	23.88	18.43	23.68	23.92	26	24,805
6	½ ton 3-12-4	38.31	35.31	15.23	24.13	27.04	20.50	27.71	26.89	42	27,884
7	Untreated	27.41	25.41	8.80	15.08	22.65	16.79	16.52	18.95	....	19,651
8	187.5 lb. nitrate of soda	22.13	20.13	8.18	16.70	20.50	15.29	18.54	17.35	— 8.4	17,991

*For description of soil see page 7.
†Cut early to plant tomatoes.

The data on which the above conclusion is drawn show strikingly the response of lettuce to liming on that soil, which was acid. From this and other work published by the Rhode Island Station this crop is usually placed in the list of vegetables that benefit from lime. Practice seems to be in line with this general conclusion, as indicated by Beattie (3).

The work of Crist (4), on the other hand, suggests that the variety of forcing lettuce, Grand Rapids, is tolerant of acidity to a high degree and is more sensitive to alkalinity than acidity. He states that lettuce "does best in a medium of growth that is distinctly acid in reaction, when the necessary nutrient materials are present in proper quantities and proportions". "The culture solution with a pH value of 5.0 gave maximum growth.... The liming of the strongly acid soil beyond the point of certain small fractional parts of the total lime requirement progressively reduced the plant's content of water and nutrient materials and thus diminished growth".

In view of the conclusions of the Rhode Island work that lime is beneficial and of the Michigan work that it is detrimental, it is of interest to note the development of Grand Rapids lettuce in the experiments here reported. While this study was not laid out with a view of studying the value of lime in particular, some comparisons can be made, altho the exact result of lime treatments cannot be measured since no plot of soil is maintained in an acid condition, or even at the neutral point. The hydrogen-ion concentration is indicated for the different plots in Table 5.

It will be recalled that the soil in Series B was moved into the greenhouse in 1922, that in Series C in 1923. Series B received a basic treatment of ground limestone at the rate of 1000 pounds per acre in 1922, but has received no more lime since. Plot 3 in Series C received ground limestone at the rate of 2 tons per acre annually. There was, of course, no leaching out of the salts in these soils since they were not exposed to the weather and the bed containing Series B has a cement bottom and Series C a puddled clay bottom. The water used was high in lime and other salts.

In Series B, as in Series C, there was no significant difference in the hydrogen-ion concentration between the plots, all being alkaline. However, in Series B the unfertilized plots (3 and 6) were highest in pH values, 8.14 and 8.23, respectively. All the other plots were treated each year with acid phosphate alone or in combination with other salts. Plot 4, which received ammonium sulfate, showed the lowest pH value, 7.66, and hence the highest hydrogen-ion concentration, but it was not greatly different from the others.

TABLE 5.—Hydrogen-ion Concentration of Soils—Series B and C*
February, 1927

House	Plot	Annual treatment per acre	Lb.	pH†
		Series B, Basic treatment 1,000 lb. limestone, 1923		
1	1	Nitrate of soda Acid phosphate	480 220	7.93
	2	Acid phosphate Muriate of potash	480 180	7.90
	3	Untreated—check		8.14
	4	Sulfate of ammonia Acid phosphate	170 480	7.66
	5	Nitrate of soda Acid phosphate Muriate of potash	220 480 180	7.96
	6	Untreated—check		8.23
	7	Acid phosphate	480	7.88
	8	Nitrate of soda Acid phosphate Muriate of potash	440 960 360	7.77
		Series C		
3	1	3-12-4 fertilizer, soil ¼ sand by volume	2,000	8.12
	2	3-12-4 fertilizer	2,000	8.01
	3	Ground limestone	4,000	8.43
	4	Manure	60,000	8.08
	5	Acid phosphate	750	7.98
	6	3-12-4 fertilizer	1,000	8.10
	7	Untreated—check		8.13
	8	Nitrate of soda	187.5	8.01

*Determined by T. C. Green, Dept. of Agronomy.
†Determined by use of the quinhydron electrode and a ratio of soil to water of 1:1.

In Series C, which did not receive a basic lime treatment, the pH values were slightly higher than in Series B. Here the untreated Plot 7 was similar to the two untreated plots in Series B. Plot 3, receiving an annual application of lime, was lowest, 8.43, but there was not the difference that might have been anticipated. Where acid phosphate was used alone the lowest pH value, 7.98, was recorded but it was so slightly different from the others as to be unimpressive.

Unfortunately, no analyses were made at the beginning of the experiment, but it may be suggested that the soil adjacent to that removed to the greenhouse runs about pH 7.6.

In view of the findings of Crist (4) and Hartwell and Damon (9) it is of interest that up to the present we are growing what appears to be normal crops of Grand Rapids lettuce on this strongly alkaline soil where suitable fertility is provided. Some plots, notably Plots 1 and 3 of Series C, are beginning to show a characteristic spotting of the leaves, which suggests the results of faulty metabolism within the plants (Fig. 4).

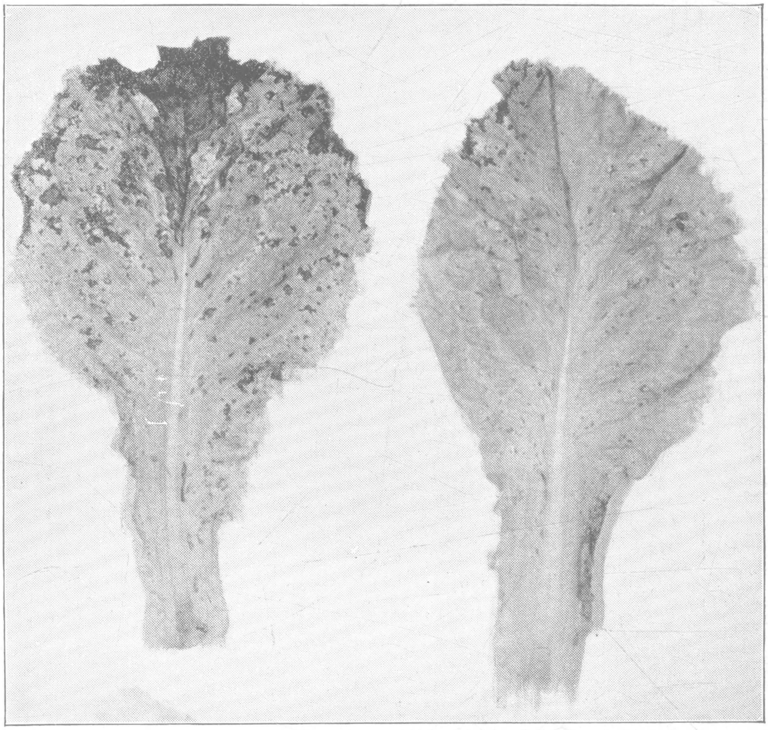


Fig. 4.—Leaf-spotting and injury to edge of leaves

This type of leaf-spotting and injury to edge of leaves (not tip-burn) occurred to some extent on certain plots. This injury may be associated with very high alkalinity as indicated in text.

DISCUSSION

In applying these findings to the growing of leaf lettuce under glass certain general observations should be made. In the first place, it is largely the scarcity and high price of animal manures that have suggested the need of studying the substitution of chemical fertilizers.

These results indicate that, on soils such as were used in these experiments, an annual application of 30 tons of manure will produce a higher yield than chemical fertilizers used alone; that, the use of chemicals in addition to such an application of manure will increase the yield of lettuce; that a ton of a 3-12-4 or a 3-7-9 fertilizer applied annually, together with a green manure crop of soybeans, may produce crops of lettuce that average 80 percent as large as those grown with the manure, and in some seasons nearly as great; that on many soils the amount of manure used may be reduced to half if it is supplemented with one-half ton of a 3-12-4 fertilizer (or one of somewhat similar analysis) and maximum commercial crops be grown.

Nitrogen used alone in Series C did not increase the yield. This is the only plot in either series where there is opportunity to measure its value, not accompanied by other elements. In Series B an increased yield was obtained from nitrogen added to phosphorus (Plot 1) or to phosphorus and potassium (Plot 8), but no greater than from potassium added to phosphorus (Plot 2). This is in harmony with the findings from other crops, that two or three elements combined usually give greater increases than one alone. On the other hand, phosphorus used alone in both Series B and C gave a definite increase in yield over the average of the untreated plots, with the exception of the first crop grown in Series B. This leads to the conclusion that phosphorus is beneficial to lettuce on this soil.

However, when a complete fertilizer was applied the results were in all cases superior to those from one or two elements only, and hence we recommend that a complete fertilizer be used in preparing the soil for lettuce. The quantity to use will depend upon the soil, but one-half ton applied in the fall for the two crops of lettuce and one-half ton prior to the tomato or cucumber crop should usually be sufficient. In order to avoid a high accumulation of salts in the soil, it is important not to overfertilize.

While comparative tests of acid, neutral, and alkaline soils were not included in these experiments, yet the increases of the limed check plots in Series B and of Plot 4 in Series C over the unlimed plot in Series C, indicate that lime is beneficial. An annual application of at least 1000 pounds per acre seems to be justified, and this is in keeping with the practice of many of the lettuce growers.

LITERATURE CITED

1. Beach, S. A. N. Y. Agr. Exp. Sta. Bul. 146:151-179.
2. Beach, S. A. and H. Hasselbring. N. Y. Agr. Exp. Sta. Bul. 208. 1901.
3. Beattie, James H. U. S. Dept. Agr. Farmers' Bul. 1418. 1924.
4. Crist, John W. Mich. Agr. Exp. Sta. Tech. Bul. 71, 74. 1926 and Cir. Bul. 89. 1926.
5. Gourley, J. H. and Roy Magruder. Ohio Agr. Exp. Sta. Bul. 377.
6. Green, S. N. Ohio Agr. Exp. Sta. Mo. Bul. Sept. 1918.
7. Green, W. J. Ohio Agr. Exp. Sta. Bul. 43: 100, 101. 1892.
8. Green, W. J. and S. N. Green. Ohio Agr. Exp. Sta. Bul. 281. 1915.
9. Hartwell, B. L. and S. C. Damon. R. I. Agr. Exp. Sta. Bul. 160. 1914.
10. Lloyd, J. H. Ill. Agr. Exp. Sta. Bul. 286. 1927.
11. Thorne, C. E. Jour. Amer. Soc. Agronomy, Vol. 18, No. 9:767-793. 1926.